SELECTION OF THE PREFERRED MANAGEMENT OPTION FOR STOCKTON BEACH – APPLICATION OF 2D COASTAL PROCESSES MODELLING

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Abstract

This paper presents an approach for selecting the preferred long term management option for further detailed design, scoping and costing for a beach suffering ongoing erosion.

There have been erosion problems for a number of years at Stockton Beach, located immediately north of the entrance to the Port of Newcastle. In response a number of analyses of historical data have been conducted to assess the problem. There had, however, been no clear understanding of the coastal processes at the beach from which to derive long term management measures.

A study was commissioned by the City of Newcastle in partnership with the NSW Government and the Newcastle Port Corporation to undertake detailed analyses of the causes of erosion at Stockton Beach and to recommend a preferred long term management option for the beach for further detailed design, scoping and costing.

The first phase of the study, analysing the coastal processes, involved the establishment and calibration of hydrodynamic, wave processes and sediment transport models. The models represented the complex coastal processes, which provided a detailed understanding of the underlying sediment transport processes.

The second phase resulted in the selection of the preferred long term management option for further detailed design, scoping and costing, which was an artificial headland combined with beach nourishment. The selection process started with the identification of a long list of potential options. The long list was reduced to a short list using a multi-parameter scoring system that assessed effectiveness in protecting the beach and considered environmental, social and economic factors. The short-listed options were then tested using the coastal processes models from the first phase and the preferred option selected.

The key to the successful outcome of the project has been the understanding of the complex coastal processes that was achieved through coastal process modelling.

Introduction

Stockton Beach is located just north of Newcastle and the mouth of the Hunter River on the mid NSW Coast. It is an extensive sandy beach which extends from the northern side of the mouth of the Hunter River northwards to the boundary of the Newcastle Local Government Area (LGA), as presented in Figure 1. Stockton Beach is an important community asset for the Hunter Coast region.

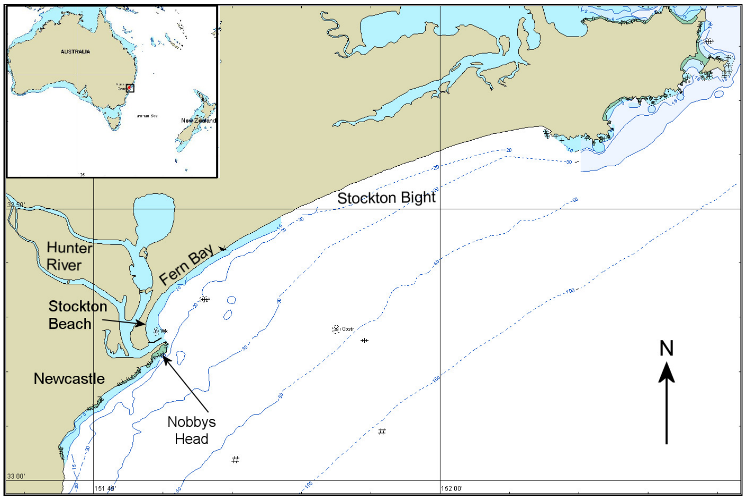

Figure 1 Location of Stockton Beach

For many years the area has been prone to erosion and, in response, a number of studies were carried out to assess these problems based on historical data. The most recent of these studies suggested that the erosion problem was progressively worsening, with significant volumes of sand having been permanently lost from the beach system (Umwelt & SMEC, 2002). There was, however, no clear understanding of the coastal processes at Stockton Beach as the findings of the previous studies were not consistent (Umwelt & SMEC, 2002). Consequently, no clear recommendations for the long term management of Stockton Beach could be made in the *Newcastle Coastline Management Plan* (Umwelt 2003) and it was stated that there should be "further detailed analysis of coastal processes off Stockton Beach and consideration of long term management options'. In response to this statement, DHI Water and Environment were engaged to prepare the *Stockton Beach Coastal Processes Study* (DHI, 2006) (the *Processes Study*) and the draft *Stockton Beach Coastal Zone Management Study* (DHI, 2009).

This paper describes the approach to understanding the complex coastal processes at Stockton Beach and the selection of the preferred long term management option for further detailed design, scoping and costing. The application of 2D coastal process models has underpinned the process of selecting the preferred long term management option for further detailed design, scoping and costing. The models provided a detailed description of the coastal processes that have led to the ongoing erosion at the beach and subsequently in testing the effectiveness of the potential options in rehabilitating and protecting the beach.

Approach

The first step was to establish coastal process models of Stockton Beach and then to use these models to simulate the ongoing processes, which then provided a detailed understanding of the dominant processes. These first steps were undertaken in the *Processes Study*. Next the potential options for the long term management were identified and evaluated, using the models and data derived from the *Processes Study*, which was undertaken in the draft *Management Study*. This approach to selecting the preferred long term management option for further detailed design, scoping and costing for Stockton Beach followed the steps for formulating a coastline management study that are outlined in the NSW Coastline Management Manual (NSW Government, 1990).

The *Processes Study* aimed to provide a comprehensive understanding of the sediment transport processes along Stockton Beach and provide quantification of the sediment budgets along the southern portion of the beach. This was undertaken through the use of both 1D and 2D coastal process models, which were established and then used to represent the ongoing coastal processes.

The draft *Management Study* commenced with an identification of the management options that could potentially address the erosive process identified in the *Processes Study*, selection of a short list of options and evaluation of the short listed options to select the preferred option. The major part of the evaluation of the short listed options was the use of the coastal process models from the *Processes Study* to simulate the performance of each option in protecting Stockton Beach from erosion. The identification and short listing of the options was based on the understanding of the ongoing processes derived from the coastal process models in the *Processes Study*.

Modelling of the Ongoing Coastal Processes

Outline

The coastal processes along Stockton Beach vary from generally simple alongshore transport patterns on the northern portion of the beach to highly complex two dimensional patterns in the southern portion of the beach where the breakwaters at the entrance the Hunter River cause variations in the incoming wave heights. A hybrid approach combining 1D and 2D models was followed to represent these processes. A 1D model was used to predict the littoral transport at the northern end of the beach, where the beach is relatively uniform with a well defined alongshore transport regime. 2D models were used to represent sediment transport at the more complex southern end of the beach, which was the focus of the study. To ensure consistency between the two modeling approaches the net littoral drift from the 2D models was equal to that from the 1D model.

1D Modelling

The littoral transport in the area not influenced by 2D effects was simulated by the littoral transport model LITDRIFT of the LITPACK suite of models. LITDRIFT is a comprehensive deterministic numerical model that computes the longshore currents, the littoral drift and the sediment budget. The model was applied to the point along the beach at which 2D effects were not likely (referred to as P2 in Figure 2) and simulated the period 1992 to 2004, which was the period of available wave data.

Wave data for input to the LITDRFIT model were transformed from the offshore Sydney Buoy (at 80m water depth at Long Reef) into the nearshore areas with a regional spectral wave model (MIKE 21 SW). This model was calibrated against local wave data collected offshore of the southern end of Stockton Beach.

A review of long term records and the results of the modeling determined that there was a net northerly longshore transport at a rate of 20,000 – 30,000 m^3/year.

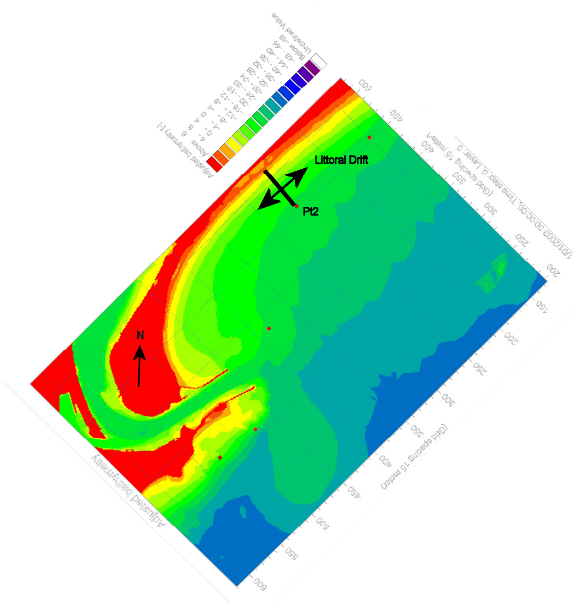

Figure 2 Location of the Point where 2D Processes are not Significant (P2)

2D Modelling

The complex coastal processes at the southern end of Stockton Beach caused by the presence of the breakwaters at the entrance to the Hunter River meant that a dynamic 2D modeling approach was required to represent the littoral processes along this section of the beach. The area covered by the 2D models is shown in Figure 3.

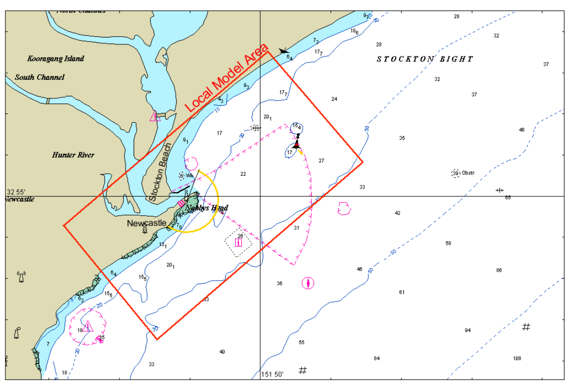

Figure 3 2D Model Area

The 2D modeling was based on the MIKE 21 suite of models and included the following components.

- A MIKE 21 PMS (parabolic mild slope) wave model was applied to simulate the nearshore wave field and the radiation stresses in the local model area. This model was applied because it included representations of the 2D wave processes that are most relevant in the Stockton area such as shoaling, refraction, wave breaking and diffraction.
- A MIKE 21 HD hydrodynamic model was applied to simulate the local flow patterns, including those derived from tidal currents and those caused by the radiation stresses obtained from the local wave model. The effects of river discharges were input from a MIKE 11 model of the river.

- The MIKE 21 ST sediment transport model was applied to simulate the sediment transport capacity in the local area caused by the currents from the HD model.

The modeling was undertaken for eight selected wave conditions that were found to be representative of average annual conditions. The boundary conditions for the MIKE 21 PMS model were provided by the MIKE 21 SW model that also provided input data for the 1D modeling. The results for each of the eight conditions were weighted based on the frequency of occurrence to calculate annual sediment transport rates. The key sediment transport pathways derived from the 2D modeling are summarised in Figure 4 and described below.

- At the entrance to the Hunter River the breakwaters interrupt the northern transport of sand along the shore from Nobby's Beach and the sand is likely to be deposited into the deeper areas of the navigation channel at the entrance to the Hunter River.

- The breakwaters provide a sheltered area on the southern end of Stockton Beach, which results in a reversal in current direction and sand is transported in a southerly direction to the area behind the northern breakwater. Low rates of deposition are predicted along the beach sections immediately north of the northern breakwater.

- At the northern end of the existing seawall there is predicted to be a nodal point, where the alongshore transport of sand splits into two directions, southwards and northwards. Further to the north, the models have predicted that there is a stretch of beach where the wave energy is focussed. These two factors have led to the areas north of the seawall being eroded as sand is transported northwards along the beach, with greater erosion occurring to the north of the wave focussing area due to increased transport along the beach.

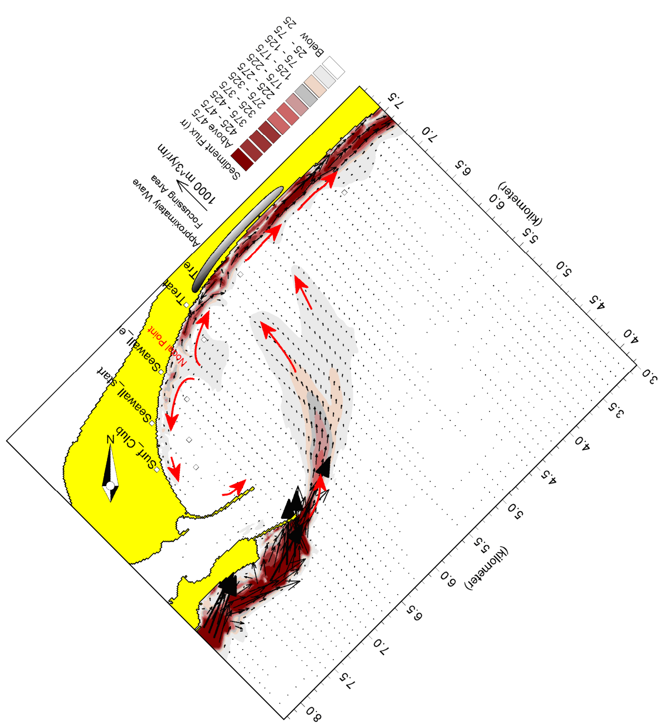

Figure 4 Predicted Annual Sediment Transport Patterns

Identification and Short Listing of Management Options for the Draft Management Study

The identification and short listing of potential options followed these steps:

- Identification of potential options to derive a comprehensive list of options;
- Screening of potential options to derive a long list of options; and
- Evaluation of the long list to derive a short list of potential options.

Identification and Screening of Options

The aim of the initial identification was to outline a comprehensive list of potential management options for further consideration. The options were identified based on the management measures identified in Chapter 5 of the NSW Coastline Management Manual (NSW Government, 1990), which included measures under the broad headings of environmental planning, development control conditions, dune management; and construction of protective works. Expanding upon each of the headings provided an initial identification of potential options. Further options that have been implemented elsewhere were added to the list of potential options, including multi-functional artificial reefs (MFARs) and beach drainage. The potential options are summarised in Table 1.

Table 1 Summary of Potential Management Options

Category	Option	Variant
	Do Nothing	
Environmental Planning	Buffer Zones	
	Restrictive Zoning	
	Planned Retreat	
	Voluntary Purchase	
Development Control Conditions	Building Setback	
	Building Type	
	Foundation Type	
	Flood Mitigation	
Dune Management	Measures to Manage a Stable Dune System	
Protective Works	Seawalls	Storm profile
	Beach Nourishment	Sand bypassing
		Onshore/Offshore
	Offshore Breakwaters	Emergent/Submerged
		Curved
		Multi-functional artificial reef
	Groynes	Emergent/Submerged
	Artificial Headland	
	Configuration Dredging	
	Beach Drainage	

The comprehensive list of potential options was subject to initial screening, based on reliability, practicality and potential community acceptance. For ‘reliability’ the option was assessed in terms of whether it would provide a solution to the particular issues at Stockton Beach and whether the option has a demonstrated track record of success in similar circumstances elsewhere. The assessment of applicability to Stockton Beach was based upon the coastal processes determined from the previous modeling. The criterion ‘practicality’ involved an assessment of whether the option was feasible to apply the option to Stockton Beach. Lastly, the potential community response to the option was considered based on available community consultation from previous studies and from the current study. Failure to meet any of the criteria meant that the option was not put forward for further assessment. The following options made the initial long list.

1. Planned retreat (coupled with voluntary purchase);
2. Beach nourishment (onshore placement for the capital nourishment);
3. Seawall (rubble mound construction);
4. Offshore breakwater (emergent, straight, shore parallel);
5. Offshore breakwater (multi-functional artificial reef);
6. Groynes (emergent); and
7. Artificial headland.

The construction of beach structures to protect sections of Stockton Beach and prevent further erosion would, however, not restore sections of the beach where serious erosion has already occurred. In addition, the structures could lead to further erosion as the beach would re-orient to a new equilibrium profile. The use of beach nourishment would restore sections of the beach, but the deposited material would not be protected from the forces that caused the original erosion. To provide improved outcomes it was recommended that a second set of options be considered that combine nourishment with protection works as follows:

8. Seawall (rubble mound construction) with nourishment;
9. Offshore breakwater (emergent, straight, shore parallel) with beach nourishment;
10. Offshore breakwater (multi-functional artificial reef) with beach nourishment;
11. Groynes (emergent) with beach nourishment; and
12. Artificial headland with beach nourishment.

The twelve long listed options were then subject to further assessment to derive a short list of options.

Derivation of Short List

The long list of options was scored against evaluation criteria in four broad categories; protection, social, environmental and economic. The aim of the scoring exercise was to identify a short list of options that would be carried forward for detailed assessment.

The provision of a separate category of ‘Protection’ acknowledges that the primary goal of the NSW Coastal Policy (DoP, 1997) is to reduce the impact of coastal hazards and that the matters to be dealt with in coastal zone management plans are ‘protecting and preserving beach environments and beach amenity’ (NSW, 1997). The primary coastal hazard at Stockton Beach is coastal erosion and so the primary objective of the options should have been to reduce the risk from coastal erosion and protect the beach. The category ‘Protection’ included assessment of beach plan protection, beach profile protection, flood protection and adjacent beach effects.

The remaining three categories of ’Social’, ’Environment’ and ’Economic’ recognised that the NSW Coastal Policy is based on the principles of Ecologically Sustainable Development (ESD) that integrate competing aims for coastal management and development (NSW, 1997). Also, the Coastal Protection Act 1979 (NSW), under which coastline management plans are made, has the principles of ESD as an object of the act. This objective of integration of factors is reflected in the NSW Coastline Management Manual where it is stated that hazard considerations should be weighed up with other factors, including social, economic, recreational, aesthetic and ecological (NSW, 1990).

Scores were assigned to each of the categories. The final score for each option was then derived based on a weighting for each of the categories, which were 40% for 'Protection' and 20% for each of the other three categories. This weighting reflected the importance of protecting the beach. The scoring in this category was largely based upon how the option would perform in response to the ongoing coastal processes that were defined in the *Processes Study*. The highest scoring five options were selected for further detailed assessment and were:

- Beach nourishment;
- Seawall with beach nourishment;
- Artificial headland with beach nourishment;
- Offshore breakwater with beach nourishment; and
- Multi-function artificial reef with beach nourishment.

Evaluation of the Short Listed Options

Outline

The aim of the assessment was to determine the coastal protection performance of the five short-listed options, the results of which provided information that was used in the selection of the preferred option for further detailed design, scoping and costing. Detailed modelling was undertaken using the models that were set up in the *Process Study*.

The approach to the modelling of the options was split into three phases:

- Review of previous findings in the Stage 1 study, which will be used to develop conceptual designs for the five options;
- Modelling of options, which has been undertaken using the models that were set up and calibrated in the Stage 1 study; and
- Analysis of the modelling results to assess the performance of the options.

The *Processes Study* findings were reviewed to provide a basis for the conceptual designs of the options. The designs were defined in sufficient detail to allow the options to be modelled. Detailed designs of the options were beyond the scope of the study and would be expected following confirmation of the preferred management option during the preparation of the *Newcastle Coastal Zone Management Plan*.

Modelling of the options was undertaken using two different modelling approaches:

- Two dimensional modelling has been undertaken of the annual average shoreline responses; and

- One dimensional modelling has been used to derive the long term shoreline responses.

The results of the modelling were analysed to determine whether modifications could be made to the conceptual designs to improve their effectiveness and to assess the performance of each option as a coast protection measure.

Conceptual Design of the Options

The conceptual designs of the options were defined to provide sufficient information to enable modeling of the options to be conducted. This included information on the beach plan and profile and the location and geometry of the structures.

Artificial Nourishment Only

The capital nourishment for artificial nourishment alone was based on providing onshore beach nourishment at the shoreface to reinstate the beach and provide an increase in the current beach width of 20m – 30m (see Figure 5). Nourishment was proposed across the beach profile from the -5m (AHD) contour up to the 2 m (AHD) level (see Figure 6). In addition, backshore nourishment was also included at the foot of the dunes to protect against short term erosion from storm events. The total sand volumes were estimated as 380,000 m^3 for the shoreface nourishment and 30,000m^3 for the backshore nourishment. It was recommended that the sand should have a grain size coarser than the existing sand to reduce initial losses and reduce the requirements for maintenance nourishment.

Figure 5 Extent of the Proposed Beach Nourishment

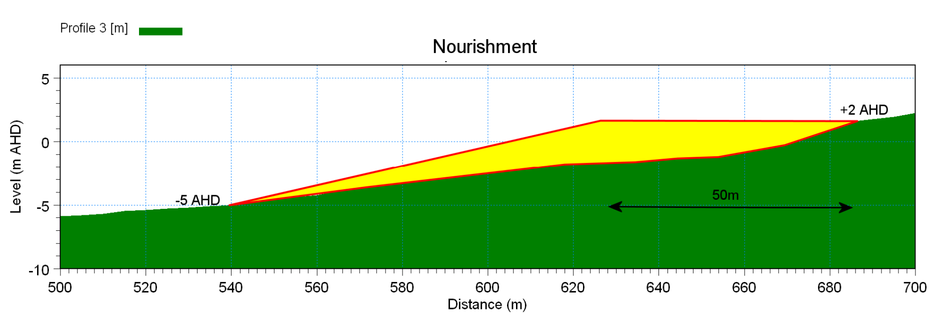

Figure 6 Cross Section of the Proposed Beach Nourishment

Seawall Combined with Artificial Beach Nourishment

In this option a revetment was proposed at the back of the foreshore to defend the coast against short term erosion, protecting important infrastructure. The maximum height was selected as 2-3m AHD with a width of 3m to 5m and a slope of 1:2 to a depth of 0m AHD (approximately mean sea level). The revetment would be covered with the nourishment sand and so would function as a passive sea defence. The extent of the seawall would cover the same length as the nourishment (see Figure 5). The proposed artificial nourishment for this option was the same as for artificial nourishment alone, which is described above.

Offshore Breakwaters with Artificial Beach Nourishment

The aim of using detached offshore breakwaters was to introduce structures to create a number of self-contained coastal cells where the shore is re-orientated towards the predominant waves to reduce or minimise sand losses and mitigate long-term erosion. The design of the scheme included for three breakwaters (see Figure 7), each of 100m length, with a crest width of 5m and side slopes of 1:3 dictated by the use of rock armour. The breakwaters would be positioned approximately 150m offshore of the beach, which aimed to only partially interrupt the longshore transport and produce salients.

The artificial beach nourishment profile for this option was originally defined to be the same as for nourishment alone. Initial 1D modeling of the long term littoral transport determined the potential beach profile, which was then adopted as the initial nourishment profile. This approach would minimise the re-orientation time for the beach. The finally adopted initial profile is shown in Figure 7.

Figure 7 Locations of Offshore Breakwaters

Artificial Headland with Artificial Beach Nourishment

It was proposed to reduce the sand losses occurring on Stockton Beach by constructing a coastal headland north of the sewage ponds area (see Figure 8) to block the predominant north-going littoral transport. This proposal would result in accumulation of sand on the southern side of the headland and some erosion north of the headland, however a significant setback line is available here that allows erosion to occur without putting infrastructure at risk. The length of the headland was set to 270m offshore of the beach, which would extend to the -9m AHD seabed contour. This depth was found in the *Process Study* to be the offshore limit of the active littoral transport area and meant that the headland would interrupt the majority of the northwards littoral drift. The structure was assumed to be rock armoured with 1:3 side slopes and a width at the shoreward end of 250m. The location and plan shape of the headland is illustrated in Figure 8.

The artificial beach nourishment profile for this option was originally defined to be the same as for nourishment alone. The results of the detailed modelling were used to revise the capital nourishment program with the aim of delivering the nourishment as close as possible to the final equilibrium beach profiles and plan form. This approach would minimise the re-orientation time for the beach and reduce the risk of undesirable erosion.

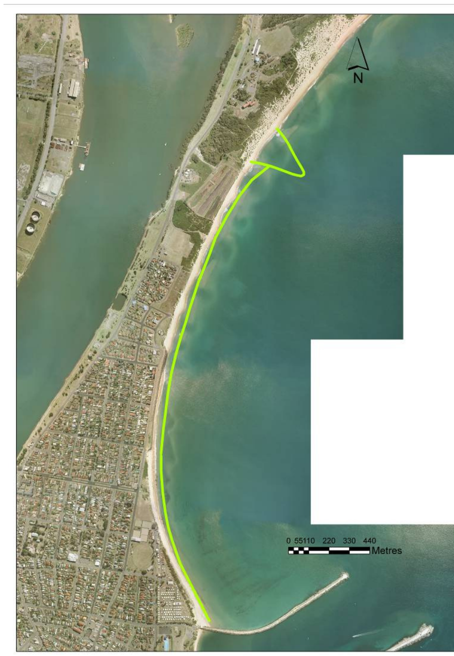

Figure 8 Layout of the Artificial Headland Option

Multi-Function Artificial Reef with Artificial Beach Nourishment

The location of the reef has been chosen north of the current erosion area so that material leaving Stockton Beach is blocked by the artificial reef, producing an accumulation area and resulting in a realignment of the beach plan. As part of this approach initial artificial nourishment is proposed to improve conditions by initially widening the beach. As for other options the final beach plan would be used as a guide to define the profile of the initial nourishment.

The design parameters of the MFAR being modelled for Stockton Beach were based on the Narrowneck artificial reef on the Gold Coast, the key features of which are:

Crest level = -0.5m LAT
Shore parallel length = 205m
Shore normal length = 290 - 450m

The layout and location of the reef are shown in Figure 9.

Figure 9 Layout of the Multi-Function Artificial Reef

Options Modelling
The effects of the options on coastal processes were simulated using two different modelling approaches:

- The MIKE 21 HD, PMS and ST models were used to simulate wave, current and sediment transport condition and derive average annual sediment transport rates; and

- The LITPACK 1D shoreline evolution model was used to derive the long term shoreline responses.

The steps in the application of the 2D models are given below:

1. Update the bathymetry in the model to represent the features of the option.
2. The MIKE 21 PMS model was used to derive the wave field and radiation stresses - input wave conditions were derived from the previously derived inshore wave climate.
3. MIKE 21 HD model was used to simulate local flow patterns, taking into account the radiation stresses from the PMS model and local currents.
4. The MIKE 21 ST model was used to simulate the sediment transport patterns caused by the local flow patterns in the HD model and the wave field from the PMS model. The results were used to derive the annual sediment transport rates.

The 2D modeling was conducted for the same eight conditions to be representative of annual average conditions, as in the *Processes Study*.

The 1D modelling was undertaken using the LITLINE model, which is part of the LITPACK suite of models. The model simulates the littoral transport in the presence of structures, based on empirical formulations of wave transformations and changes in sediment transport patterns due to coastal structures. The model was used to simulate the shoreline response for the 12 year period from March 1992 to August 2004, which was previously simulated in the *Processes Study*.

The results from the 2D modeling were presented for typical summer and winter conditions to show the wave climate, current speeds and sediment transport rates. Average annual sediment transport rates were calculated from the eight representative 2D scenarios, as in the *Processes Study*. The 1D modeling provided the long term beach profile for the 12 year simulation period. A sample of the modeling results for the artificial headland are shown in Figure 10.

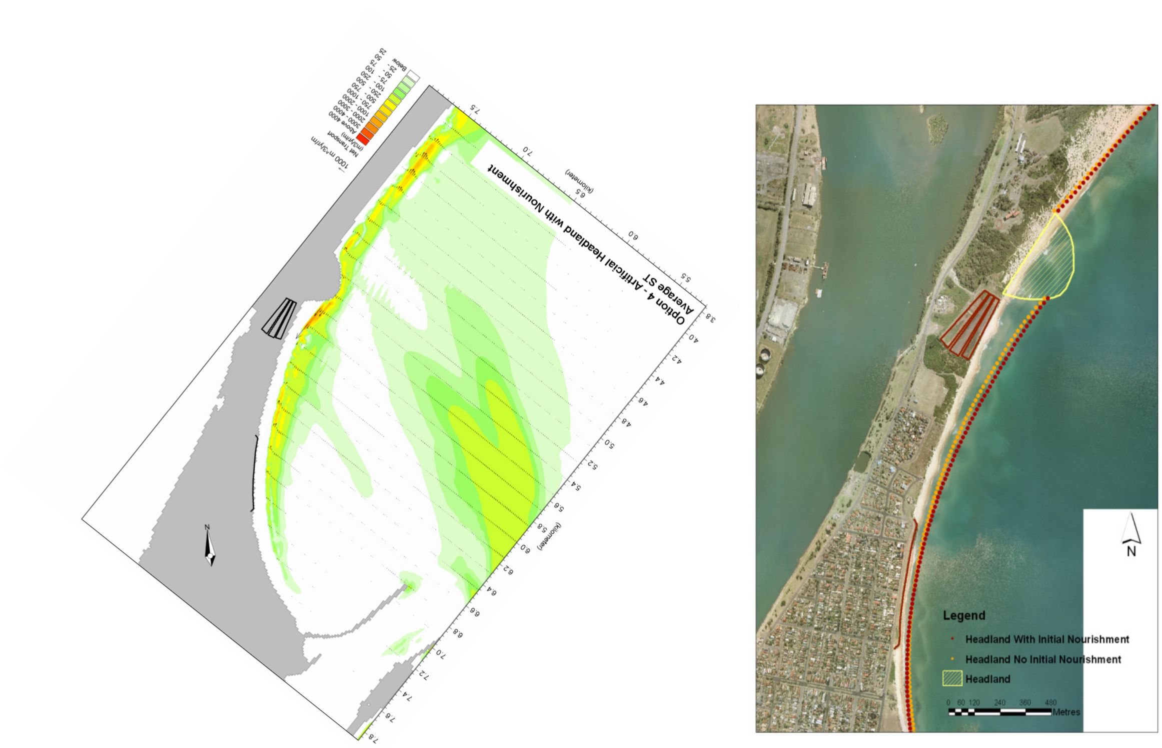

Figure 10 Average Annual Sediment Transport (left) and Long Term Beach Profile (right) for the Artificial Headland

The results of the modeling were assessed in terms of the effects of the structures on coastal processes and as coast protection measures. The following summarises the key findings of the analysis for each of the options considered.

Artificial beach nourishment alone resulted in only localised changes to wave and current conditions and so the long term erosive processes would continue, which means that maintenance nourishment would be required. There were not significant effects on downdrift areas because the supply of sand to these areas would be maintained, and the modelling even predicted accretion to the north due to the increased availability of sand on Stockton Beach.

The performance of the seawall combined with artificial nourishment in terms of coastal processes and coastal protection would be largely the same as nourishment alone because the seawall would remain covered as the width of the beach is sufficient to mitigate both long term and short term erosion. The seawall would thus act as a passive coast protection measure, but would provide additional protection against severe storm events.

The offshore breakwaters resulted in localised changes in wave conditions in the vicinity of the breakwaters, with reductions in wave activity in the lee of the structures, which resulted in a modification of the longshore currents that included reductions in the currents on southern sections of the beach. This option was found to effectively mitigate the long term erosion and resulted in a stable long term profile, with increased beach width in the lee of the structures. There was, however, predicted to be localised erosion on the downdrift side of the central breakwater, but the predicted beach recession is small as the structure still allows sediment to pass along the beach.

The artificial headland resulted in a re-orientation of the beach profile so that the waves approached the shoreline at an almost perpendicular angle. This then resulted in uniform flow conditions along the beach and a reduction in longshore currents. The long term erosion was then comprehensively mitigated through reductions in littoral transport and re-orientation of the beach to a stable profile. There was, however, predicted to be some erosion to the beach immediately to the north of the headland caused by the headland blocking the littoral sand transport, although the extent of the erosion was reduced by increasing the initial nourishment volume to encourage early bypassing of the headland.

The wave conditions in the vicinity of the artificial reef were significantly modified, while elsewhere the wave field remained similar to existing conditions. There were only local modifications to the longshore currents in the vicinity of the reef and so the long term erosion was only partially mitigated. Significant wave breaking around the reef was found to induce a complex two dimensional flow pattern that has large cross-shore currents.

Selection of the Preferred Option for Detailed Design, Scoping and Costing

The selection of the preferred option in the draft *Management Study* for further detailed design, scoping and costing was based on a qualitative weighing up of the merits and drawbacks of each of the short listed options, considering the option's performance as a coastal protection measure, environmental effects, social factors, and economic factors. The primary factor in considering each of the options was the performance of the measure as a coastal protection option. The evaluation resulted in the selection of the artificial headland combined with artificial beach nourishment. This was because the option provided the most effective coast protection measure, with reduced maintenance requirements. The option had also received broad support at a community workshop and would provide opportunities for development of additional amenity value. These merits were sufficient to select this option ahead of other less costly options.

The City of Newcastle is currently undertaking detailed design, scoping and costing for the artificial headland option, which will contribute to the preparation of the *Newcastle*

Coastal Zone Management Plan. The *Newcastle Coastal Zone Management Plan* will identify the council adopted management options for mitigating erosion at Stockton Beach.

Conclusions

The application of 2D coastal process modelling was fundamental in selecting the preferred long term management option for detailed design, scoping and costing for Stockton Beach, which has been suffering from ongoing erosion. The application of the models first provided an understanding of the complex coastal processes along the beach, which involved interactions between waves, currents and coastal structures. This understanding allowed for appropriate options to be short listed for detailed investigation. The models were then used to simulate the each of the selected options and the results analysed in terms of the effects of the structures on coastal processes and as coast protection measures to mitigate existing erosion problems. The results of the modeling provided clear quantitative evidence of the artificial headland combined with beach nourishment as the most effective measure.

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